in-situ ^{3}He SEOP polarizer for the new time of flight spectrometer TOPAS

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Abstract.

We report on the new on-beam SEOP **[1]** polarizer that will be in use for the new thermal time of flight spectrometer with polarization analysis TOPAS **[2],** the system uses a ^{3}He cell with an opacity of 40.5 suitable for neutron wavelength of λ=0.7Å and will be polarized in-situ using SEOP technique. The optical pumping will be done by two frequency narrowed laser array bars using an ultra-compact volume Bragg grating. AFP and NMR **[3],** are also available on this system to flip and control the polarization on-beam. During the first on-beam test of the system the ^{3}He cell reached a maximum polarization of 78.5% from unpolarized neutron transmission measurements, the total transmission through the polarizer at this ^{3}He polarization was 23.8% with a calculated neutron polarizing power of 97.6% for 0.895 Å neutrons. The full system is now ready for use, and actually operational for long time experiment on POLI **[4]**.

1. **Introduction**

Based on the experience gained from long time (5years) running on-beam analyzer for MARIA [5] reflectometer, we have prototyped end tested a new in-situ SEOP polarizer for TOPAS. A simple rectangular SEOP magic-box style magnetic cavity similar to those in [6, 8] is used. The box design has been resized for the smaller beam diameter required for an incident beam of about D=6 cm. The resulting cavity is 30 cm tall by 20 cm wide and 50 cm long. the field will be along the 30cm direction and be co-linear with the guide fields of TOPAS to prevent depolarization of the very fast 0.7 Å minimum neutron wavelength to be used there. Two VBG narrowed DAB lasers as mentioned before will be used [9,10], one for the front 7.5 cm and the other for the back 7.5 cm of the 15 cm long cell needed to polarized the TOPAS incident beam. Several ^{3}He NSF cells with 3 bar ^{3}He and 6 cm diameter and 15 cm length have been produced and tested for lifetime, lifetimes in excess of 200 hours are achieved.

The system is placed inside a closed box cooled by roof mounted chiller to keep the working temperature stable at 35˚C for the optical pumping lasers and optics despite the 210˚C inside the oven, the box prevents also direct view to lasers for safety raisons. An automated guide changer will be used to move the system in and out of the beam to allow the unpolarized neutron option as shown in figure1.

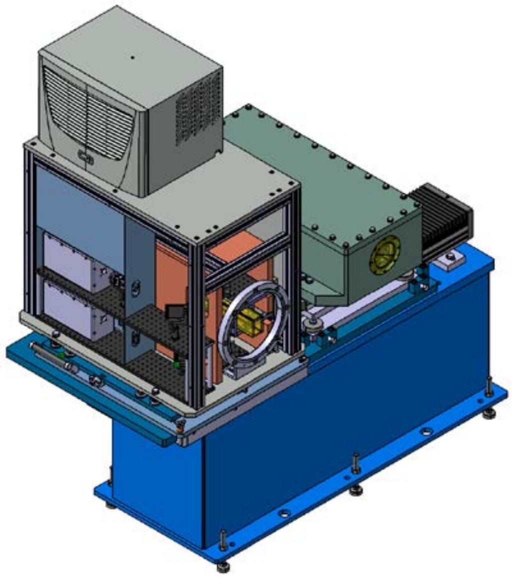

Figure 1. *The on-beam polarizer and guide changer*

2. **The Magnetic cavity**

The magnetic cavity has been constructed and tested for the polarized ^{3}He magnetic lifetime (Figure 2-a). (***permanent magnet and current driven magnetic cavities using mu-metal to create highly homogeneous magnetic field is described in separate paper in this proceeding***). Initial experimental optimization was performed with the 3-axis hall probe mounted to a rail to make 1-D longitudinal field maps of the magnetic cavity. After this optimization a 5 cm diameter 15 cm long SEOP cell with 3 bar ^{3}He pressure was polarized externally in our lab and placed in the magnetic cavity aiming the measurements of the ^{3}He lifetime**.** The cell was placed in the centre of the magnetic cavity and the decay of the relative polarisation was monitored using the NMR system. The free induction decay (FID) of the longitudinal magnetization is periodically monitored, typically every hour: ^{3}He polarisation is proportional to the amplitude of the FID signal. The exponential decay fit of the amplitude-time dependence gives a value of T_1. Figure 2-b shows the result of the measured ^{3}He relaxation time lifetime. We obtain a T_1 of 185h. In order to test the influence of the oven components on the relaxation time the same test was performed, this time with a cell placed inside the oven as in the real optical pumping procedure. The results are shown in the same plot; we can see that the oven does not affect the decay of the He3 polarization.

After subtracting of the contribution for the intrinsic lifetime of the cell which includes ^{3}He dipole-dipole relaxation [11] and the wall relaxation of this cell [12] taking into account the T_1 of 220h measured for the same cell in perfect magnetic field, we obtain the measured ^{3}He magnetic lifetime of 1395 hours for 3 bar pressure or the averaged over the cell equivalent magnetic field gradient of about 5×10^{-4} cm^{-1}.

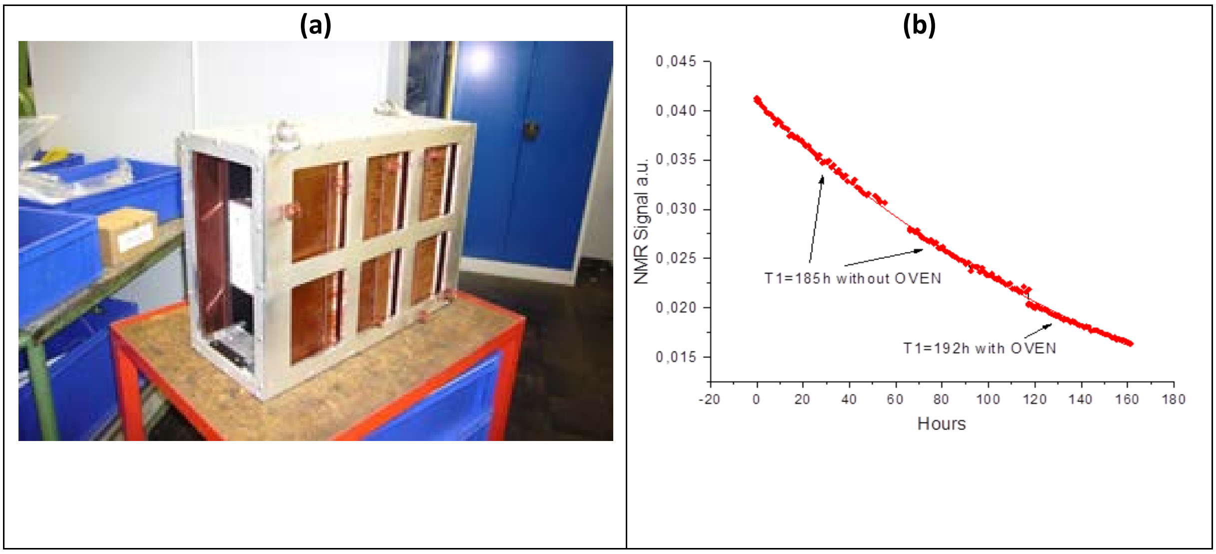

Figure 2. *a- The magnetic cavity with oven and ^{3}He cell inside. b- ^{3}He cell relaxation time. Measured ^{3}He relaxation time of 185 hours for 3 bar ^{3}He cell placed inside the magnetic cavity. Subtraction of the cells self-relaxation time yields a cell averaged equivalent gradient of 5×10^{-4}cm^{-1}.*

3. New oven concept

as shown in figure 3, the oven was designed in such a way to host a 15cm long and 5 cm large He3 cell, and fit inside the magic cavity as described before. The heating system use static air heated by electric cartridge heaters mounted in copper heat sinks. these stainless steel electric cartridge heaters (220 V CSS-series from Omega Engineering) now used for heating have not been found to decrease expected ^{3}He polarization, or room temperature T_1 lifetime. There is indeed some magnetic components to these heaters, namely the nickel plated lead wires, however in our installation, the heater is placed inside the before mentioned copper heat-sinks, about 10 cm away from the cell as shown in figure3, with the wires exiting away from the cell

Figure 3. *The new oven with He3 cell inside the magnetic cavity*

position. The copper heat sink is grounded to limit pickup of electrical noise by the NMR FID system [3]. To meet the requirement of temperature accuracy and stability needed for optical pumping The system was tested during one week. PID control system was used to supply the heaters and regulate the oven temperature, several temperature sensors were placed at the surface of the cell and at different position inside the oven. After only 25 minutes of heating up, the system could reach the temperature of 250˚C at the heat sink position and 210˚C at the cell position, the temperature was stable to within 0.5˚C as shown in figure 4.

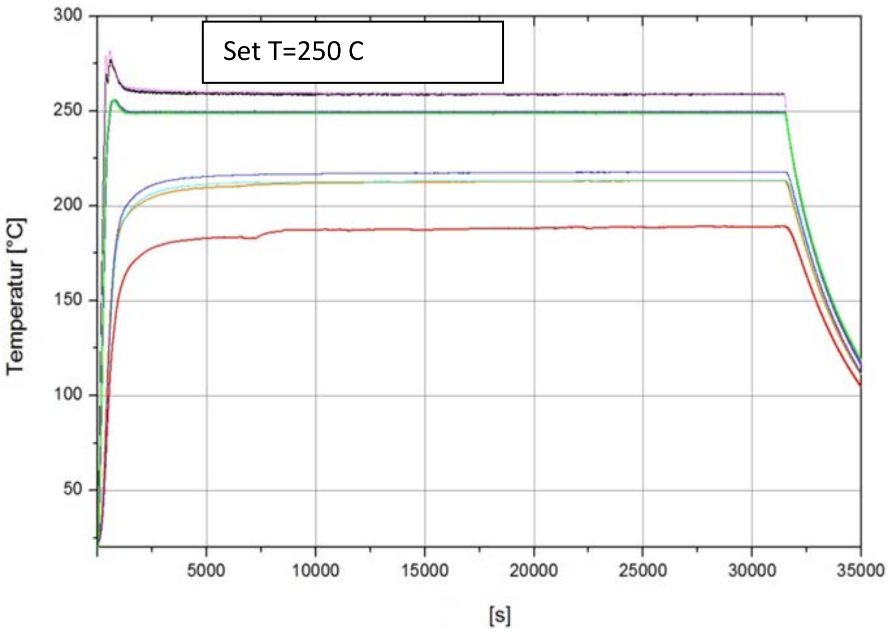

Figure 4. *Test of the oven temperature stability*

4. AFP and NMR Control system

NMR free induction decay (FID) and adiabatic fast passage (AFP) flipping are both available on this system as shown in figure 5. The FID allows one to monitor the ^{3}He polarization over time and characterize the optical pumping parameters such as the spin-up time constant and cell lifetime. Our FID system conserves the phase information of the ^{3}He precession and thus also allows us to probe whether the ^{3}He is in the up or down state. It is a single-coil pulse and receive system using in-house developed analogue switch and signal conditioning amplifier [13,14].

The AFP allows the ^{3}He NSF to double as a high performance, wide area neutron flipper as well. The AFP program is an all digitally generated pulse amplified using a house built power amplifier with a 120 Vpp output from 5 kHz up to 100 kHz [14,15]. For the case of in-situ optical pumping via SEOP, the handedness of the circular polarization, and therefore the alkali-metal polarization, must be in phase with the direction of the ^{3}He spin. For this purpose, we use liquid crystal variable wave retarders to switch between left and right polarization by applying a TTL pulse to a house built analogue liquid crystal (LC) wave plate driver. All the NMR devices and the switching of the LC retarders are accomplished with a program written in Python which has a web-browser interface that can be accessed remotely over a web server or via IP protocols. The program controls a 1.25 MHz Lab-view DAQ card using the National Instruments DAQmx 8.0 driver library which runs in either Linux or Windows.

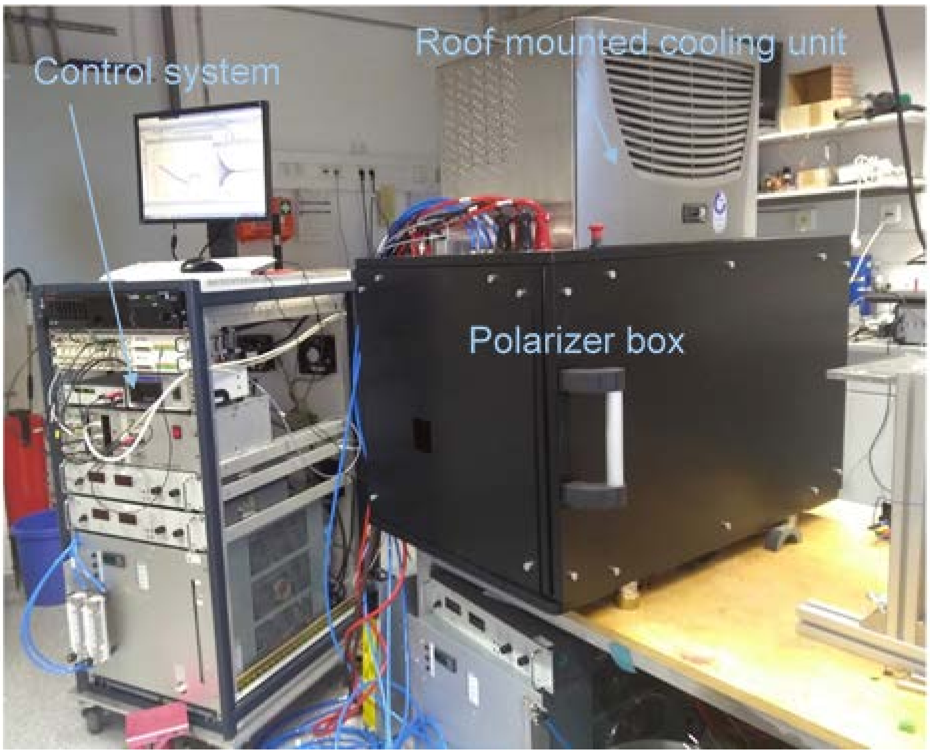

Figure 5. *The polarizer box with roof mounted cooling unit and the control system*

5. Laser systems upgrade

Our laser systems have also been upgraded. Formerly diode array bars (DAB) with external cavities using Littrow-type configuration were used [9] as narrow-band optical pumping light has been shown to provide the best SEOP performance. However, it was found later that a new compact method using chirped volume Bragg gratings, CVBG, provides a higher absolute ^{3}He polarization [10]. Additionally, CVBG narrowed lasers give higher laser intensity output for laser diodes of the same power, and contain much fewer optical elements making the cavity more compact, stable and robust for long term operations required for in-situ ^{3}He polarizer applications. A photo of the new laser cavity is shown in figure 6, where the laser mounted inside a newly designed compact box for mounting the laser and cavity optics is shown, as well as external connections to the power cables and cooling water. This box also provides environmental protection and increased laser security. Two such lasers are used to pump the 15cm long ^{3}He NSF cell used here for this in-situ polarizer.

Figure 6. *A picture the laser-box of the current volume Bragg grating narrowed laser configuration. This optical setup fit in a custom made enclose box to enclose and mount all the optics and provide connections to power cable and cooling water.*

6. Result of the on-beam test at POLI

After several tests and off line optimization, the compact cavity was installed at POLI instrument at MLZ for absolute measurements of the ^{3}He polarization using the neutron transmission technique [17]. The cell was pre-polarized in the experimental hall near the POLI instrument, a temperature of 215°C was used in the oven to obtain a 7 hour 3He polarization time constant, or "spin-up" time. This fully polarized the cell in one day. The oven temperature is very stable and the optics and magic box where also very stable despite the warm temperatures in the guide hall thanks to the roof mounted chiller which cooled and stabilised the system to a temperature of under 35°C. Polarization was then held stable for three days at which point it was moved into the POLI beam without shutting it down, followed by the neutron measurements. On POLI the in-situ polarizer was installed as an incident beam polarizer, followed by a transmission monitor, the cryopad sample environment with a single crystal sample, and a MEOP polarized analyser cell was installed in the standard POLI configuration for analysis of the reflected neutron beam polarization. A 0.895 Å neutron wavelength was used. The available space was very limited and precise and rather complex positioning with crane was need.

As mentioned before, the ^{3}He cell used has an opacity of 41.5 bar-cm of 3He, and reached a maximum polarization of 78.5% from unpolarized neutron transmission measurements. The initial polarization after the transport to the beam was 74% but thanks to the optical pumping it built up to 78.5% over night and remained stable on the POLI instrument (figure 7). The total transmission through the polarizer at this 3He polarization was 23.8% with a neutron polarizing power (calculated) of 97.6% for 0.895 angstrom neutrons. A fresh analyzer cell HL2 from the FRM2 MEOP station [18,19] was installed in the Decpol magnetostatic cavity for analysis of the polarization from a nuclear Bragg peak mounted in the Croystat inside the 0-field polarimeter Cryopad. The analyzer cell provided by FRM2 had an opacity of 37 bar-cm with a 3He polarization of 67.6% and neutron transmission of 20.5% measured 3.5 hours after the insertion into the Decpol, resulting in a neutron polarization analyzing efficiency of 92.8%.

After optimisation of the magnetic fields a combined maximum flipping ratio of 17 was obtained, corresponding to a total neutron polarization of 89.0%, only slightly lower than the product of the polarizer and analyzer (97.6%*92.8%=90.6%) obtained from transmission measurements.

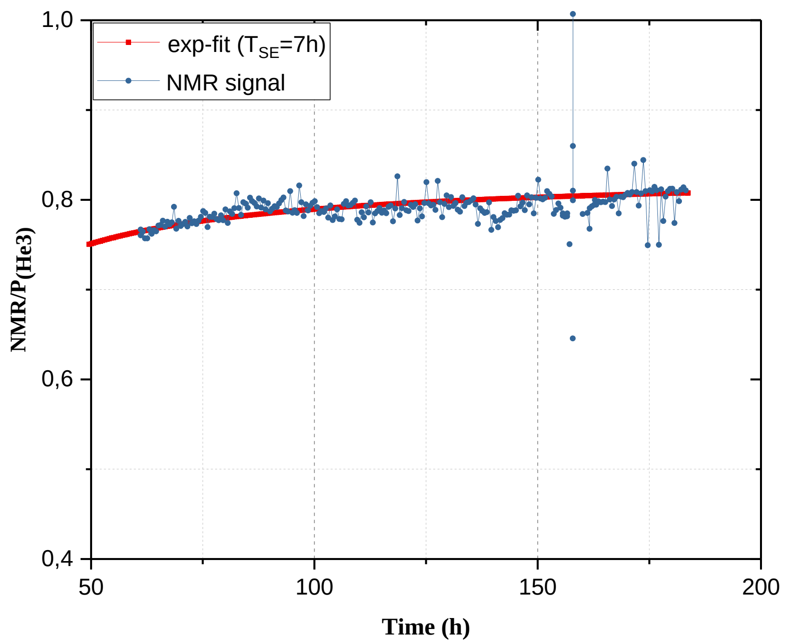

Figure 7. *The 3He polarization as function of time obtained during on-beam test at POLI*

7. Conclusions

We have designed, prototyped, and tested an in-situ SEOP ^{3}He polarizer for TOPAS spectrometer. The magnetic cavity design assures the relative field gradients of 5.10^{-4} cm^{-1}. all components easily achieved the desired goals, the first on-beam test gave maximal He3 polarization of 78.5%. The total transmission through the polarizer at this ^{3}He polarization was 23.8% with a neutron polarizing power of 97.6% for 0.895 Å neutrons.

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